Physics

HP COMPUTER CURRICULUM

Waves

TEACHERS ADVISOR

HEWLETT PACKARD

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Hewlett-Packard
Computer Curriculum Series

physics
TEACHER'S ADVISOR

waves

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11000 Wolfe Road
Cupertino, California 95014

HP 5951-4440

October 1972

Prepared for press by
Graphic Associates

The Hewlett-Packard Computer Curriculum Series represents the published results of a Curriculum Development project sponsored by the Data Systems Division of Hewlett-Packard Company. This project is under the directorship of Jean H. Danver.

This material is designed to be used with any Hewlett-Packard system with the BASIC programming language such as the 9830A Educational BASIC, and the 2000 and 3000 series systems.

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INTRODUCTION

This Physics Set of the Hewlett-Packard Computer Curriculum Series consists of a set of Student Lab Book and a corresponding Teacher's Advisor. It was designed to help meet the need for computer-oriented problems in physics, providing students an opportunity to use a computer as a problem solving tool within a particular subject matter area.

The materials are designed for flexible use as desired by the individual instructor. The material and exercises in this unit are intended as an "enrichment" experience in the field of waves. Waves are introduced by teaching the student to plot sine and cosine functions on a printing device such as a teleprinter or thermal printer. An x-y plotter would be cleaner and faster, but most users will have only a mechanical printer available. If you should have an x-y plotter, show your students how to use it. Graphical results are emphasized throughout the unit in two ways: the students are asked to make quick sketches of anticipated results and to write programs to plot those results. Once the graphing technique is explained, standing waves are presented, with accompanying exercises that illustrate (via the teleprinter) the effect on the wave of different wavelengths and frequencies. Traveling waves are investigated in a similar manner. The final topic covered is the superposition of sinusoids, with exercises involving interference and intensity. Since these topics are generally not covered in introductory texts, the use of this manual should not compete with your text. Instead, it can be used to supplement and enrich in any fashion you choose.

The degree of difficulty of the material is dependent upon the amount of assistance which you choose to provide. With no assistance, the better physics student should be challenged. However, given a good deal of assistance, any physics student should be able to work out the exercises with no great difficulty. The level of the material is determined by the assumption that students taking introductory physics will be quite capable as a group.

The Lab Book provides text material and programming exercises for the students, a sample program and advanced problems. The Teacher's Advisor contains an example of a program to solve each exercise and a brief discussion of the important elements of the exercise.

For best results, you should study all the solutions until you are certain you have a complete grasp of the general methods. This should be done before assigning the material to the class. Generally, the exercises are cumulative so that as techniques are developed they are used in subsequent exercises. Therefore, you will probably wish to proceed through the exercises in the order in which they are given.

You will undoubtedly think of different programming methods or techniques as you study the example programs. Encourage the students to do the same. There are no *approved* solutions. You may have a computer system with features which would improve the programs. At this level, there is no need for emphasis on the efficiency of a student's program. The important question is, does it work?

REVIEW OF TRIGONOMETRY

The Lab Book briefly reviews the trigonometry required for the investigation of waves by discussing circular functions. You may wish to continue this discussion beyond sine and cosine.

GRAPHING FUNCTIONS

You should pay particular attention in your classroom discussion to the sine plot program listed in Figure 2, since modifications of this program are utilized in all the exercises. Make sure that your students understand this program completely.

EXERCISE 1 – A Graph of the Cosine Function

The cosine function is plotted by changing only the DEF statement in line 120 in the program in Figure 2. In part (c) the student should notice that the cosine of an angle is the same as the sine of the same angle plus $\pi/2$ radians. In part (d), the student should see immediately that the amplitudes and periods of the two functions are identical. Study of Figure 1 shows this clearly.

EXERCISE 2 – A Change in the Period, y = Sin(2t)

Again the only change required from the program in Figure 2 is in the DEF statement. The balance of the exercise follows without difficulty.

EXERCISE 3 – A Change in the Period, y = Sin(t/2)

Same method as in Exercise 2.

EXERCISE 4 – Discovery

As in the exercises above, this requires only a modification of the DEF statement in line 120 of the program listed in Figure 2. This exercise is very important and will be referred to in later sections. The important idea is that a constant phase angle merely displaces the picture of the function, or is equivalent to starting the point on the unit circle in Figure 1 somewhere other than on the positive x axis.

EXERCISE 5 – Sum of Two Sinusoids with the Same Period

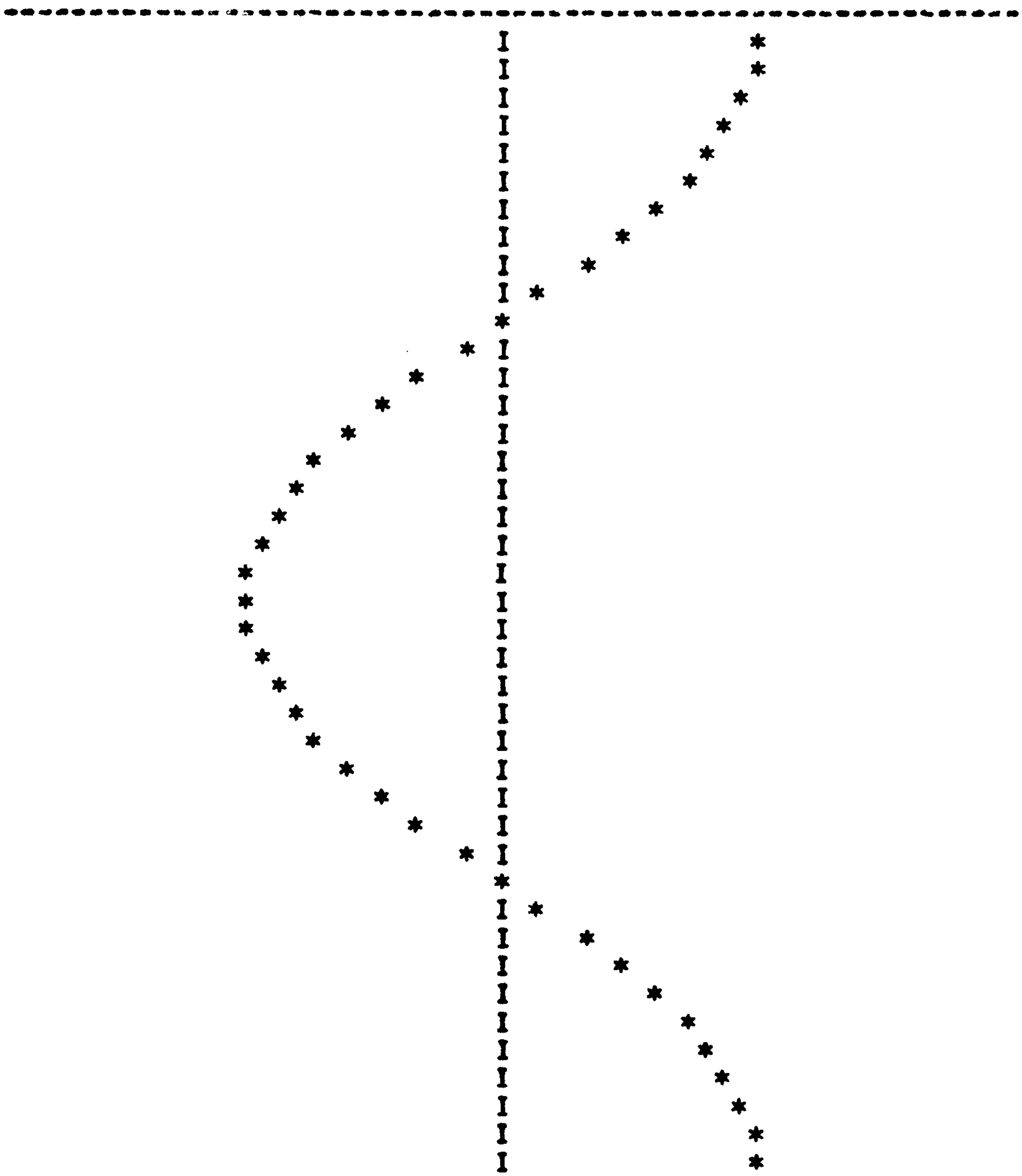
This exercise is designed to show that the sum of two sinusoids with identical amplitudes and periods is a new function with different amplitude but identical period.

EXERCISE 6 – A New Function

In this exercise, the program in Figure 2 must be modified to include the argument of the sine function as a function of x. No results are included here as the picture will be exactly the same as for a function of t. The students should understand that all that is involved is a substitution of symbols.

```
120  DEF FNA(T) = COS(T)

RUN
```



```
READY
```

y = Cost

Exercise 1

```
120  DEF FNA(T) = SIN(2*T)

RUN

-------------------------------------------------------------
                              *
                              I    *
                              I        *
                              I           *
                              I             *
                              I              *
                              I             *
                              I           *
                              I        *
                              I    *
                              *
                         *    I
                     *        I
                  *           I
                *             I
               *              I
                *             I
                  *           I
                     *        I
                         *    I
                              *
                              I    *
                              I        *
                              I           *
                              I             *
                              I              *
                              I             *
                              I           *
                              I        *
                              I    *
                              *
                         *    I
                     *        I
                  *           I
                *             I
               *              I
                *             I
                  *           I
                     *        I
                         *    I
                              *

READY
```

y = Sin(2t)

Exercise 2

```
120  DEF FNA(T) = SIN(T/2)
RUN

-------------------------------------------------------------
                             *
                             I*
                             I *
                             I   *
                             I    *
                             I     *
                             I      *
                             I       *
                             I        *
                             I         *
                             I          *
                             I          *
                             I           *
                             I            *
                             I            *
                             I             *
                             I             *
                             I              *
                             I              *
                             I              *
                             I              *
                             I              *
                             I              *
                             I              *
                             I             *
                             I             *
                             I            *
                             I            *
                             I           *
                             I          *
                             I          *
                             I         *
                             I        *
                             I       *
                             I      *
                             I     *
                             I    *
                             I   *
                             I *
                             I*
                             *

READY
```

y = Sin(t/2)

Exercise 3

```
120   DEF FNA(T) = SIN(T+.78540)

RUN

------------------------------------------------------------
                              I          *
                              I           *
                              I            *
                              I             *
                              I              *
                              I              *
                              I              *
                              I             *
                              I            *
                              I           *
                              I          *
                              I        *
                              I      *
                              I    *
                              I *
                              *
                            * I
                         *    I
                       *      I
                     *        I
                   *          I
                  *           I
                 *            I
                *             I
               *              I
               *              I
               *              I
                *             I
                 *            I
                  *           I
                   *          I
                     *        I
                       *      I
                         *    I
                            * I
                              *
                              I *
                              I    *
                              I      *
                              I        *
                              I          *

READY
```

$y = \text{Sin}(t + \pi/4)$

Exercise 4

```
120  DEF FNA(T) = COS(T)+SIN(T)
RUN

-------------------------------------------------------------
                              I              *
                              I                *
                              I                  *
                              I                   *
                              I                    *
                              I                    *
                              I                    *
                              I                   *
                              I                  *
                              I                *
                              I              *
                              I           *
                              I         *
                              I      *
                              I  *
                              *
                           *  I
                       *      I
                    *         I
                  *           I
               *              I
             *                I
           *                  I
          *                   I
         *                    I
         *                    I
         *                    I
          *                   I
           *                  I
             *                I
               *              I
                  *           I
                    *         I
                       *      I
                           *  I
                              *
                              I  *
                              I      *
                              I         *
                              I           *
                              I              *

READY
```

y = cos(t) + Sin(t)

Exercise 5

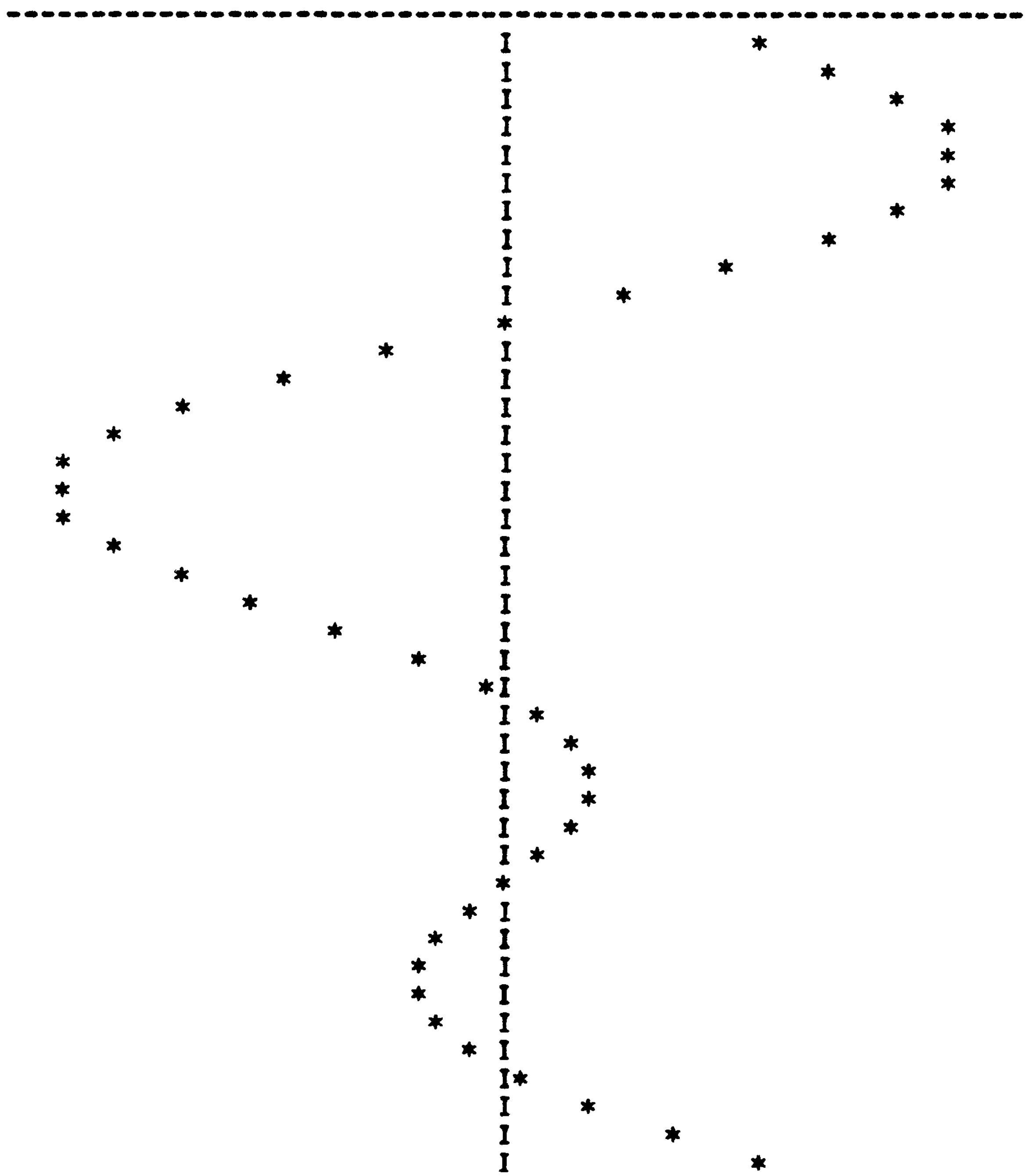
EXERCISE 7 – Discovery

Careful examination of the unit circle in Figure 1, plus the application of the Pythagorean theorem, gives the useful trigonometric identity that the sum of the squares of the sine and cosine of any angle is equal to 1. The students should try to discover this on their own and then use the computer to prove their results.

EXERCISE 8 – Sum of Two Sinusoids with Different Periods

You should not expect your students to predict what will happen in this exercise. Let them discover the results on the computer. They should note that something drastic has happened in that the period of the sum of the two functions does not seem to be well-behaved. What is taking place is the beat phenomenon. You may want to explain the beat phenomenon at this point. If so, devise an exercise in which you extend the range of the plot and make the frequencies of the two functions close together. The beat phenomenon will be clearly defined.

```
120  DEF FNA(T) = COS(T)+SIN(2*T)
RUN
```



```
READY
```

y = cos(t) + sin(2t)

Exercise 8

STANDING WAVES

EXERCISE 9 – Standing Wave Computation

The maximum amplitude of the standing wave is 2. The wavelength is 20, and the cyclical frequency is $1/2\pi$ cycles per second. The most important part of this exercise is (d). The student should discover one of the most important properties of a standing wave—that all points on the wave go through the equilibrium position at the same time.

```
LIST
100  REM STANDING WAVE
110  LET S=10
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=2*SIN(P*X/10)*COS(T*P)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              *
                              I  *
                              I     *
                              I        *
                              I           *
                              I             *
                              I               *
                              I                 *
                              I                  *
                              I                   *
                              I                   *
                              I                   *
                              I                  *
                              I                 *
                              I               *
                              I             *
                              I           *
                              I        *
                              I     *
                              I  *
                              *

READY
```

Exercise 9(a)

```
RUN
?.25
 ------------------------------------------------------------
                              *
                              I *
                              I   *
                              I     *
                              I       *
                              I         *
                              I          *
                              I            *
                              I            *
                              I             *
                              I             *
                              I             *
                              I            *
                              I            *
                              I          *
                              I         *
                              I       *
                              I     *
                              I   *
                              I *
                              *

READY
```

Exercise 9(b)

```
RUN
?.5
 -------------------------------------------------------------
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *

READY
```

Exercise 9(c)

```
RUN
?.75
 -------------------------------------------------------------
                               *
                             * I
                           *   I
                         *     I
                       *       I
                     *         I
                    *          I
                  *            I
                  *            I
                 *             I
                 *             I
                 *             I
                  *            I
                  *            I
                    *          I
                     *         I
                       *       I
                         *     I
                           *   I
                             * I
                               *

READY
```

Exercise 9(d)

```
RUN
?1
 ------------------------------------------------------------
                              *
                           *  I
                        *     I
                     *        I
                  *           I
                *             I
              *               I
            *                 I
           *                  I
          *                   I
          *                   I
          *                   I
           *                  I
            *                 I
              *               I
                *             I
                  *           I
                     *        I
                        *     I
                           *  I
                              *

READY
```

Exercise 9(e)

EXERCISE 10 – Standing Wave Computation

This is essentially the same problem as in Exercise 9, except that the wavelength is now 10.

```
LIST
100  REM STANDING WAVE
110  LET S=10
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=2*SIN(P*X/5)*COS(T*P)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              *
                              I     *
                              I           *
                              I               *
                              I                  *
                              I                   *
                              I                  *
                              I               *
                              I           *
                              I     *
                              *
                        *     I
                  *           I
              *               I
           *                  I
          *                   I
           *                  I
              *               I
                  *           I
                        *     I
                              *

READY
```

Exercise 10(a)

```
RUN
?.5
 ------------------------------------------------------------
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 10(b)

```
RUN
?1
 ------------------------------------------------------------
                              *
                        *     I
                  *           I
              *               I
           *                  I
          *                   I
           *                  I
              *               I
                  *           I
                        *     I
                              *
                              I     *
                              I           *
                              I               *
                              I                  *
                              I                   *
                              I                  *
                              I               *
                              I           *
                              I     *
                              *

READY
```

Exercise 10(c)

EXERCISE 11 – Standing Wave Computation

The maximum amplitude is 3, the wavelength is 20/3, and the cyclical frequency is 1 cycle per second.

```
LIST
100  REM STANDING WAVE
110  LET S=7
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=3*SIN(3*P*X/10)*COS(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              *
                              I         *
                              I                *
                              I                    *
                              I                   *
                              I              *
                              I     *
                           *  I
                  *           I
           *                  I
         *                    I
           *                  I
                  *           I
                           *  I
                              I     *
                              I              *
                              I                   *
                              I                    *
                              I                *
READY                         I         *
                              *
```


Exercise 11(a)

```
RUN
?.25
-------------------------------------------------------------
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 11(b)

```
RUN
?.5
-------------------------------------------------------------
                              *
                   *          I
            *                 I
        *                     I
         *                    I
              *               I
                       *      I
                              I  *
                              I         *
                              I                *
                              I                  *
                              I                *
                              I         *
                              I  *
                       *      I
              *               I
         *                    I
        *                     I
            *                 I
                   *          I
                              *

READY
```

Exercise 11(c)

EXERCISE 12 – Nodes

*The nodes are at x = 0, 2.5, 5, 7.5, and 10. Use the program from Exercise 11 changing line 150 to: 150 DEF FNA(X) =10*SIN(4*P*X/10)* COS(50*P*T).*

```
LIST
100  REM STANDING WAVE
110  LET S=2
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=10*SIN(4*P*X/10)*COS(50*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?70
 ------------------------------------------------------------
                              *
                              I           *
                              I                  *
                              I                  *
                              I           *
                              *
                  *           I
           *                  I
           *                  I
                  *           I
                              *
                              I           *
                              I                  *
                              I                  *
                              I           *
                              *
                  *           I
           *                  I
           *                  I
                  *           I
                              *
READY
```

ADVANCED EXERCISES

EXERCISE 13 – Superposition of Standing Waves (Different Frequencies)

This is a good exercise in trigonometry for your better students. They may or may not be able to discover the answer on the computer. The result is a standing wave with a frequency equal to the average of the two original frequencies but whose amplitude is a function of both x and t.

```
LIST
100  REM STANDING WAVE
110  LET S=2
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=5*SIN(P*X/10)*COS(2*P*T)
151  DEF FNB(X)=5*SIN(P*X/10)*COS(P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*(FNA(X)+FNB(X))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 -------------------------------------------------------------
                               *
                               I  *
                               I     *
                               I        *
                               I           *
                               I             *
                               I                *
                               I                  *
                               I                   *
                               I                    *
                               I                    *
                               I                    *
                               I                   *
                               I                  *
                               I                *
                               I             *
                               I           *
                               I        *
                               I     *
                               I  *
                               *

READY
```

Exercise 13(a)

```
RUN
?.25
 -------------------------------------------------------------
                               *
                               I*
                               I *
                               I  *
                               I   *
                               I    *
                               I     *
                               I     *
                               I      *
                               I      *
                               I      *
                               I      *
                               I      *
                               I     *
                               I     *
                               I    *
                               I   *
                               I  *
                               I *
                               I*
                               *

READY
```

Exercise 13(b)

```
RUN
?1
 -------------------------------------------------------------
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 13(c)

```
RUN
?.5
 -------------------------------------------------------------
                              *
                            * I
                           *  I
                         *    I
                        *     I
                       *      I
                      *       I
                     *        I
                    *         I
                    *         I
                    *         I
                    *         I
                    *         I
                     *        I
                      *       I
                       *      I
                        *     I
                         *    I
                           *  I
                            * I
                              *

READY
```

Exercise 13(d)

*EXERCISE 14 – **Superposition of Standing Waves (Different Wavelengths)***

The result of this superposition is a standing wave with the same frequency as the original waves, but with a modulated amplitude that is a function of x.

```
LIST
100  REM STANDING WAVE
110  LET S=2
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=5*SIN(P*X/10)*COS(2*P*T)
151  DEF FNB(X)=5*SIN(P*X/5)*COS(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*(FNA(X)+FNB(X))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              *
                              I    *
                              I        *
                              I            *
                              I              *
                              I                *
                              I                 *
                              I                *
                              I              *
                              I            *
                              I         *
                              I      *
                              I   *
                              I*
                             *I
                           *  I
                          *   I
                          *   I
                           *  I
                            * I
                              *

READY
```

Exercise 14(a)

```
RUN
?.25
 ------------------------------------------------------------
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 14(b)

```
RUN
?.5
 -------------------------------------------------------------
                              *
                         *    I
                     *        I
                 *            I
               *              I
             *                I
            *                 I
             *                I
               *              I
                 *            I
                    *         I
                       *      I
                          *   I
                             *I
                              I*
                              I  *
                              I   *
                              I   *
                              I  *
                              I *
                              *

READY
```

Exercise 14(c)

EXERCISE 15 – Superposition of Standing Waves (Different Wavelengths and Frequencies)

The result here cannot be identified with the characteristics of a standing wave.

```
LIST
100  REM STANDING WAVE
110  LET S=2
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=5*SIN(P*X/10)*COS(P*T)
151  DEF FNB(X)=5*SIN(P*X/5)*COS(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*(FNA(X)+FNB(X))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              *
                              I    *
                              I        *
                              I            *
                              I              *
                              I                *
                              I                 *
                              I                *
                              I              *
                              I            *
                              I         *
                              I      *
                              I   *
                              I*
                             *I
                           *  I
                          *   I
                          *   I
                           *  I
                            * I
                              *

READY
```

Exercise 15(a)

```
RUN
?.5
 ------------------------------------------------------------
                              *
                           *  I
                        *     I
                      *       I
                    *         I
                    *         I
                    *         I
                      *       I
                        *     I
                           *  I
                              *
                              I  *
                              I     *
                              I       *
                              I         *
                              I         *
                              I         *
                              I       *
                              I     *
                              I  *
                              *

READY
```

Exercise 15(b)

```
RUN
?1
 ------------------------------------------------------------
                              *
                              I *
                              I  *
                              I   *
                              I   *
                              I  *
                              I*
                             *I
                          *   I
                       *      I
                    *         I
                 *            I
               *              I
             *                I
            *                 I
             *                I
               *              I
                 *            I
                     *        I
                         *    I
                              *

READY
```

Exercise 15(c)

EXERCISE 16 – Trigonometric Superposition

See any text on trigonometry for the necessary identities.

TRAVELING WAVES

EXERCISE 17 – Traveling Wave Computation

The phase velocity is 20/π. When t = 0.5, the wave should have moved 10/π units from its position at t = 0. Examination of the printouts shows that this is indeed true. Recall that there is an asterisk printed out every 0.5 distance units.

```
LIST
100  REM TRAVELING WAVE
110  LET S=10
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=2*COS(2*T-P*X/10)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              I                   *
                              I                   *
                              I                  *
                              I                 *
                              I               *
                              I             *
                              I           *
                              I        *
                              I     *
                              I  *
                              *
                           *  I
                        *     I
                     *        I
                  *           I
                *             I
              *               I
            *                 I
           *                  I
          *                   I
          *                   I

READY
```

Exercise 17(a)

```
RUN
?.5
 ------------------------------------------------------------
                              I          *
                              I            *
                              I              *
                              I                *
                              I                  *
                              I                   *
                              I                   *
                              I                   *
                              I                  *
                              I                 *
                              I                *
                              I              *
                              I            *
                              I         *
                              I      *
                              I   *
                              I*
                            * I
                         *    I
                      *       I
                   *          I

READY
```

Exercise 17(b)

```
RUN
?1
 ------------------------------------------------------------
                      *       I
                         *    I
                            * I
                              I*
                              I   *
                              I      *
                              I         *
                              I           *
                              I              *
                              I                *
                              I                 *
                              I                  *
                              I                   *
                              I                   *
                              I                   *
                              I                  *
                              I                *
                              I               *
                              I             *
                              I          *
                              I       *

READY
```

Exercise 17(c)

EXERCISE 18 – Traveling Wave Computation

This is the same as Exercise 17, except the phase velocity is now 5/π.

```
LIST
100  REM TRAVELING WAVE
110  LET S=20
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=COS(T+P*X/5)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              I                   *
                              I                  *
                              I               *
                              I           *
                              I     *
                              *
                        *     I
                  *           I
              *               I
           *                  I
          *                   I
           *                  I
              *               I
                  *           I
                        *     I
                              *
                              I     *
                              I           *
                              I               *
                              I                  *
                              I                   *

READY
```

Exercise 18(a)

```
RUN
?.5
 ------------------------------------------------------------
                              I                 *
                              I             *
                              I        *
                              I  *
                          *   I
                    *         I
               *              I
            *                 I
          *                   I
          *                   I
            *                 I
                *             I
                     *        I
                           *  I
                              I   *
                              I         *
                              I              *
                              I                 *
                              I                   *
                              I                   *
                              I                 *

READY
```

Exercise 18(b)

```
RUN
?1
 -------------------------------------------------------------
                              I          *
                              I     *
                             *I
                       *      I
                 *            I
             *                I
           *                  I
          *                   I
           *                  I
               *              I
                   *          I
                         *    I
                              I*
                              I      *
                              I            *
                              I                *
                              I                  *
                              I                   *
                              I                  *
                              I              *
                              I          *

READY
```

Exercise 18(c)

EXERCISE 19 – Superposition of Traveling Waves

If enough pictures are plotted in this exercise, the two traveling waves can clearly be seen to cancel each other out, then reinforce each other, and so on. This is a good example of interference of traveling waves.

```
LIST
100  REM TRAVELING WAVE
110  LET S=10
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=COS(T+P*X/5)
151  DEF FNB(X)=COS(T-P*X/5)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*(FNA(X)+FNB(X))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 -------------------------------------------------------------
                              I                   *
                              I                  *
                              I               *
                              I           *
                              I     *
                              *
                        *     I
                  *           I
              *               I
           *                  I
          *                   I
           *                  I
              *               I
                  *           I
                        *     I
                              *
                              I     *
                              I           *
                              I               *
                              I                  *
                              I                   *

READY
```

Exercise 19(a)

```
RUN
?1
 -------------------------------------------------------------
                              I          *
                              I         *
                              I        *
                              I     *
                              I  *
                              *
                        *     I
                     *        I
                  *           I
                 *            I
                *             I
                 *            I
                  *           I
                     *        I
                        *     I
                              *
                              I  *
                              I     *
                              I        *
                              I         *
                              I          *

READY
```

Exercise 19(b)

```
RUN
?2
 ------------------------------------------------------------
                      *       I
                      *       I
                       *      I
                         *    I
                           *  I
                              *
                              I  *
                              I    *
                              I      *
                              I       *
                              I       *
                              I       *
                              I      *
                              I    *
                              I  *
                              *
                           *  I
                         *    I
                       *      I
                      *       I
                      *       I

READY
```

Exercise 19(c)

EXERCISE 20 – Traveling Gaussian Wave

This exercise illustrates that traveling waves need not be sinusoids. The example chosen here is a gaussian curve. Some students may note that this is the familiar bell curve. If so, you might choose to go on and perhaps show what happens when the denominator of the exponent is modified.

```
LIST
100  REM TRAVELING WAVE
110  LET S=20
120  LET L=10
130  INPUT T
140  LET P=3.14159
150  DEF FNA(X)=EXP(-((T-X)/2)↑2)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.0001 STEP .5
210  LET Y=INT(S*FNA(X)+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              I                   *
                              I                  *
                              I               *
                              I          *
                              I      *
                              I   *
                              I *
                              I*
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 29(a)

```
RUN
?2
 ------------------------------------------------------------
                              I      *
                              I          *
                              I               *
                              I                  *
                              I                   *
                              I                  *
                              I               *
                              I          *
                              I      *
                              I   *
                              I *
                              I*
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 20(b)

```
RUN
?5
 -------------------------------------------------------------
                               *
                               *
                               *
                               I*
                               I *
                               I   *
                               I      *
                               I          *
                               I               *
                               I                  *
                               I                   *
                               I                  *
                               I               *
                               I          *
                               I      *
                               I   *
                               I *
                               I*
                               *
                               *
                               *

READY
```

Exercise 20(c)

SUPERPOSITION OF SINUSOIDS

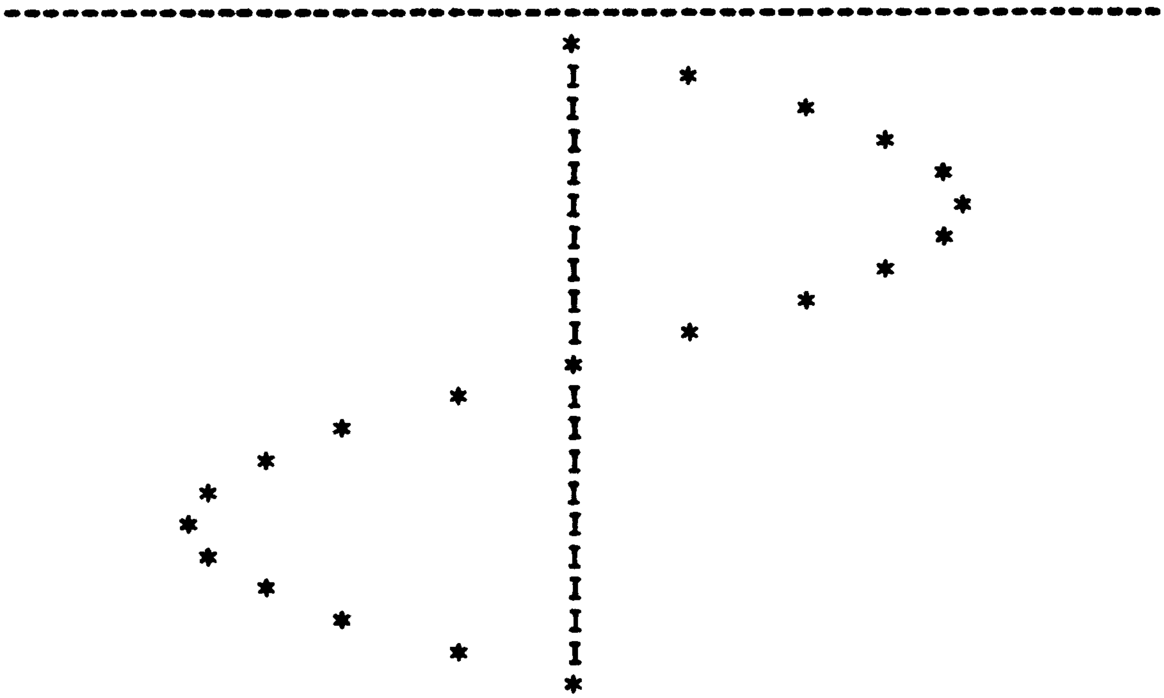
EXERCISE 21 – Interference of Sine Waves

This is a very useful exercise. All texts discuss constructive and destructive interference of sinusoids, but this exercise allows us to watch the process gradually take place as the phase angle is changed. You will probably want to place a great deal of emphasis upon this exercise.

```
LIST
100  REM SINUSOID SUPERPOSITION
110  LET S=10
140  LET P=3.14159
145  INPUT A1
146  LET A=A1*P
150  DEF FNA(T)=SIN(2*P*T+A)
151  DEF FNB(T)=SIN(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR T=0 TO 1.0001 STEP 5.00000E-02
210  LET Y=INT(S*(FNA(T)+FNB(T))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT T
999  END

READY
```

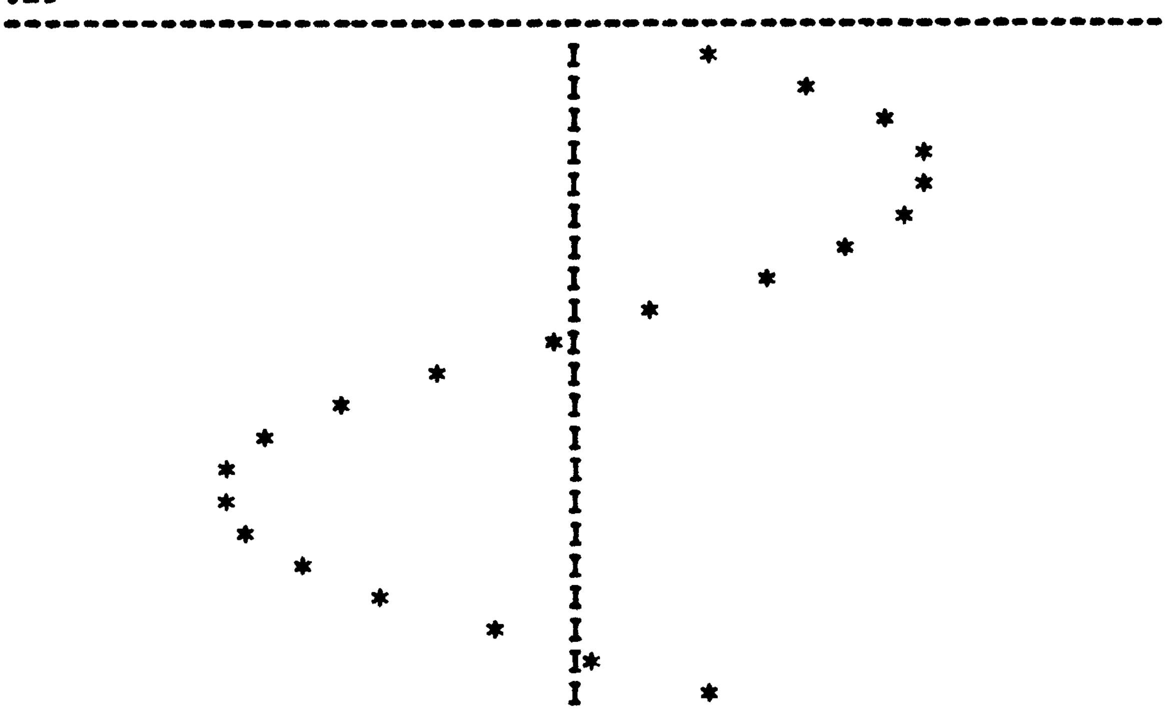
```
RUN
?0
```



```
READY
```

Exercise 21(a)

```
RUN
?.25
```



```
READY
```

Exercise 21(b)

```
RUN
?.5
------------------------------------------------------------
                              I         *
                              I            *
                              I             *
                              I             *
                              I            *
                              I         *
                              I     *
                              I *
                            * I
                        *     I
                    *         I
                 *            I
                *             I
                *             I
                 *            I
                    *         I
                        *     I
                            * I
                              I *
                              I     *
                              I         *

READY
```

Exercise 21(c)

```
RUN
?.75
------------------------------------------------------------
                              I      *
                              I       *
                              I      *
                              I      *
                              I    *
                              I  *
                              I*
                            * I
                          *   I
                        *     I
                       *      I
                      *       I
                       *      I
                       *      I
                         *    I
                           *  I
                             *I
                              I *
                              I   *
                              I     *
                              I      *

READY
```

Exercise 21(d)

```
RUN
?1
 ------------------------------------------------------------
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *
                              *

READY
```

Exercise 21(e)

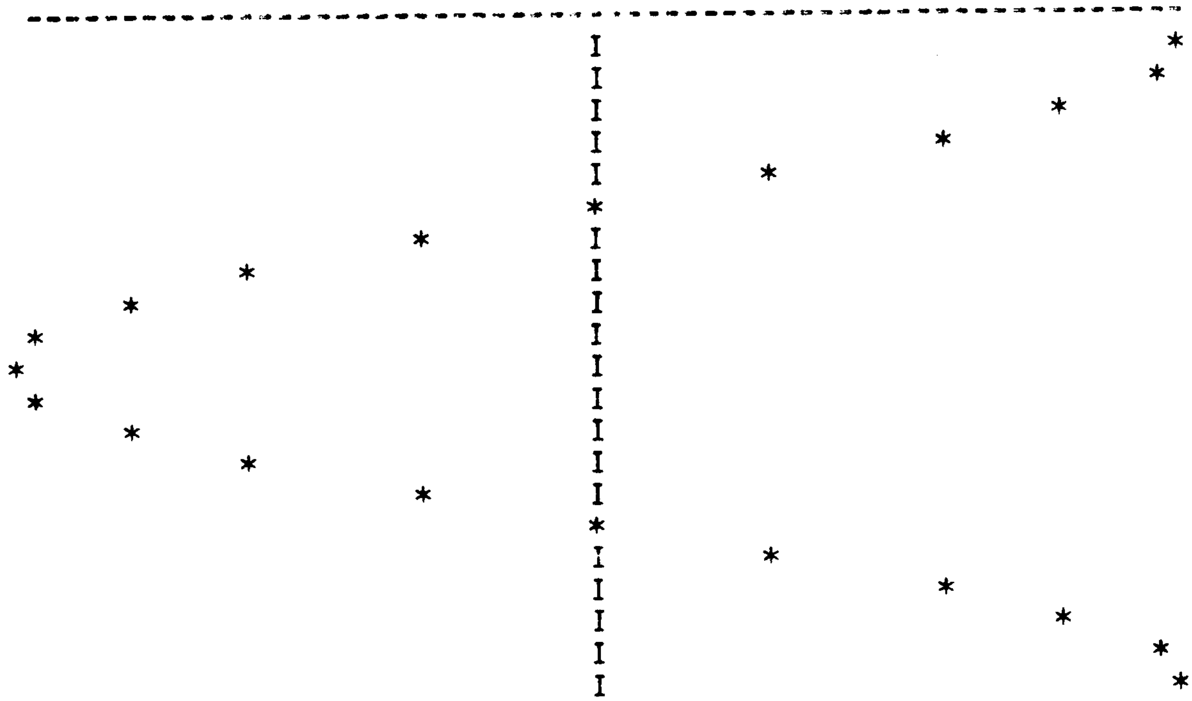
EXERCISE 22 – Interference of Cosine Waves

This exercise shows the relationship between the sine functions in Exercise 21 and the cosine functions.

```
LIST
100  REM SINUSOID SUPERPOSITION
110  LET S=10
140  LET P=3.14159
145  INPUT A1
146  LET A=A1*P
150  DEF FNA(T)=2*COS(2*P*T+A)
151  DEF FNB(T)=COS(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR T=0 TO 1.0001 STEP 5.00000E-02
210  LET Y=INT(S*(FNA(T)+FNB(T))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT T
999  END

READY
```

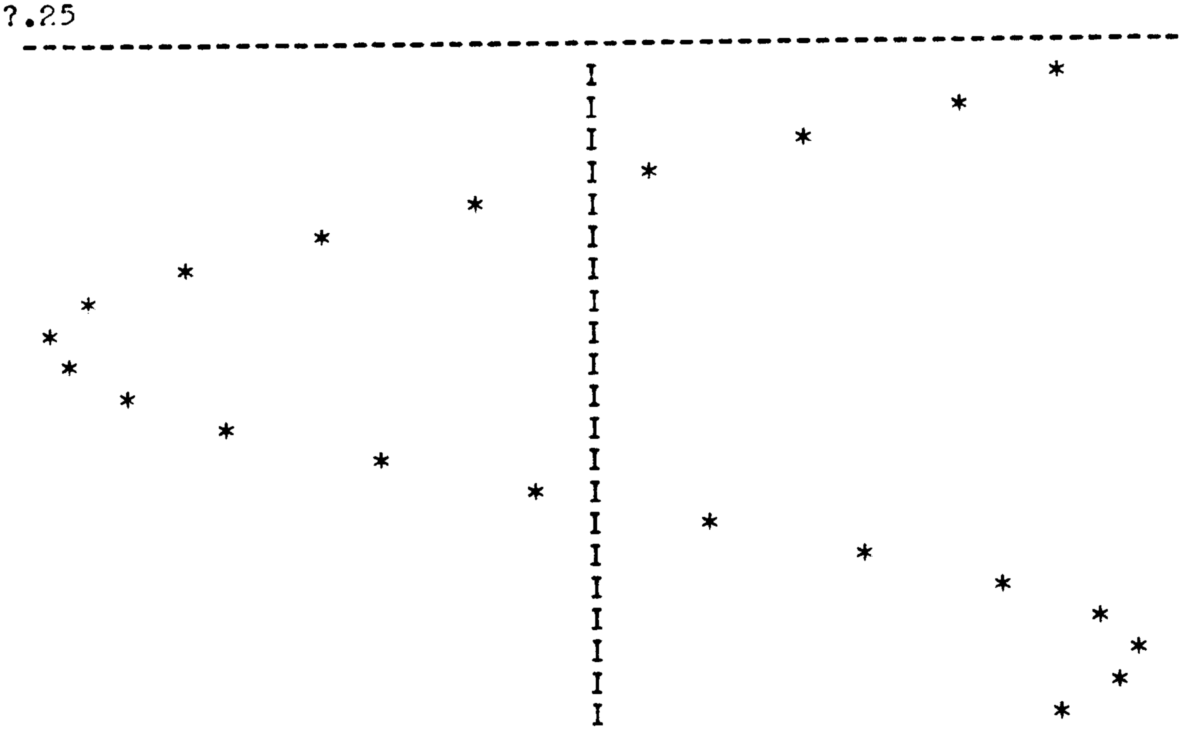
```
RUN
?0
```



```
READY
```

Exercise 22(a)

```
RUN
?.25
```



```
READY
```

Exercise 22(b)

```
RUN
?.5
 ------------------------------------------------------------
                              I         *
                              I  *
                          *   I
                    *         I
              *               I
          *                   I
        *                     I
        *                     I
          *                   I
              *               I
                    *         I
                           *  I
                              I   *
                              I         *
                              I               *
                              I                   *
                              I                     *
                              I                     *
                              I                   *
                              I               *
                              I         *

READY
```

Exercise 22(c)

```
RUN
?.75
 ------------------------------------------------------------
                          *   I
                      *       I
                  *           I
                *             I
               *              I
                *             I
                  *           I
                     *        I
                         *    I
                              *
                              I   *
                              I       *
                              I           *
                              I             *
                              I              *
                              I             *
                              I           *
                              I        *
                              I    *
                              *
                          *   I

READY
```

Exercise 22(d)

```
RUN
?1
 ------------------------------------------------------------
                    *         I
                    *         I
                      *       I
                        *     I
                           *  I
                              *
                              I  *
                              I     *
                              I       *
                              I         *
                              I         *
                              I         *
                              I       *
                              I     *
                              I  *
                              *
                           *  I
                        *     I
                      *       I
                    *         I
                    *         I

READY
```

Exercise 22(e)

EXERCISE 23 – Interference of Sine and Cosine Waves

This exercise combines the properties of Exercises 21 and 22.

```
LIST
100  REM SINUSOID SUPERPOSITION
110  LET S=10
140  LET P=3.14159
145  INPUT A1
146  LET A=A1*P
150  DEF FNA(T)=SIN(2*P*T+A)
151  DEF FNB(T)=COS(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR T=0 TO 1.0001 STEP 5.00000E-02
210  LET Y=INT(S*(FNA(T)+FNB(T))+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT T
999  END

READY
```

```
RUN
?0
 ------------------------------------------------------------
                              I        *
                              I           *
                              I            *
                              I            *
                              I           *
                              I        *
                              I    *
                              I *
                            * I
                        *     I
                    *         I
                 *            I
                *             I
                *             I
                 *            I
                    *         I
                        *     I
                            * I
                              I *
                              I    *
                              I        *

READY
```

Exercise 23(a)

```
RUN
?.25
 ------------------------------------------------------------
                              I               *
                              I                *
                              I                *
                              I              *
                              I          *
                              I     *
                              I*
                          *   I
                    *         I
                *             I
             *                I
            *                 I
            *                 I
              *               I
                  *           I
                       *      I
                             *I
                              I  *
                              I        *
                              I            *
                              I               *

READY
```

Exercise 23(b)

```
RUN
?.5
 ------------------------------------------------------------
                              I                   *
                              I                  *
                              I               *
                              I           *
                              I     *
                              *
                        *     I
                  *           I
              *               I
           *                  I
          *                   I
           *                  I
              *               I
                  *           I
                        *     I
                              *
                              I     *
                              I           *
                              I               *
                              I                  *
                              I                   *

READY
```

Exercise 23(c)

```
RUN
?.75
 ------------------------------------------------------------
                              I                *
                              I             *
                              I         *
                              I   *
                             *I
                       *      I
                  *           I
              *               I
            *                 I
            *                 I
             *                I
                *             I
                    *         I
                          *   I
                              I*
                              I      *
                              I           *
                              I               *
                              I                 *
                              I                 *
                              I                *

READY
```

Exercise 23(d)

```
RUN
?1
 ------------------------------------------------------------
                              I         *
                              I     *
                              I *
                            * I
                        *     I
                    *         I
                 *            I
                *             I
                *             I
                 *            I
                    *         I
                        *     I
                            * I
                              I *
                              I     *
                              I         *
                              I            *
                              I             *
                              I             *
                              I            *
                              I         *

READY
```

Exercise 23(e)

```
RUN
?1.25
 ------------------------------------------------------------
                              I  *
                              I*
                            * I
                          *   I
                        *     I
                       *      I
                      *       I
                       *      I
                       *      I
                         *    I
                           *  I
                             *I
                              I *
                              I   *
                              I     *
                              I      *
                              I       *
                              I      *
                              I      *
                              I    *
                              I  *

READY
```

Exercise 23(f)

```
RUN
?1.5
 -------------------------------------------------------------
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *
                               *

READY
```

Exercise 23(g)

EXERCISE 24 – Intensity

Let the student discover the mathematically obvious fact that the intensity is always positive. This exercise ties in well with material on interference patterns.

```
LIST
100  REM SINUSOID SUPERPOSITION
110  LET S=5
140  LET P=3.14159
145  INPUT A1
146  LET A=A1*P
150  DEF FNA(T)=SIN(2*P*T+A)
151  DEF FNB(T)=SIN(2*P*T)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR T=0 TO 1.0001 STEP 5.00000E-02
210  LET Y=INT(S*(FNA(T)+FNB(T))↑2+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*"; TAB(30);"I"
290  NEXT T
999  END

READY
```

```
RUN
?0
 -------------------------------------------------------------
                              *
                              I *
                              I      *
                              I            *
                              I                 *
                              I                   *
                              I                 *
                              I            *
                              I      *
                              I *
                              *
                              I *
                              I      *
                              I            *
                              I                 *
                              I                   *
                              I                 *
                              I            *
                              I      *
                              I *
                              *

READY
```

Exercise 24(a)

```
RUN
?.25
 -------------------------------------------------------------
                              I  *
                              I      *
                              I           *
                              I               *
                              I                *
                              I              *
                              I         *
                              I    *
                              I*
                              *
                              I *
                              I      *
                              I           *
                              I               *
                              I                *
                              I              *
                              I         *
                              I    *
                              I*
                              *
                              I *

READY
```

Exercise 24(b)

```
RUN
?.5
 -------------------------------------------------------------
                              I    *
                              I       *
                              I         *
                              I         *
                              I       *
                              I    *
                              I *
                              *
                              *
                              I *
                              I    *
                              I       *
                              I         *
                              I         *
                              I       *
                              I    *
                              I *
                              *
                              *
                              I *
                              I    *

READY
```

Exercise 24(c)

```
RUN
?.75
 -------------------------------------------------------------
                              I  *
                              I  *
                              I  *
                              I *
                              I*
                              *
                              *
                              *
                              I*
                              I *
                              I  *
                              I  *
                              I  *
                              I *
                              I*
                              *
                              *
                              *
                              I*
                              I *
                              I *

READY
```

Exercise 24(d)

```
RUN
?1
 ----------------------------------------------------------------------
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *
                                  *

READY
```

Exercise 24(e)

EXERCISE 25 – Discovery

The function described by the Fourier series is a square wave. When 20 terms are included, the square wave is clearly defined. Even though the students cannot be expected to understand the mathematics of a Fourier series, they can have great fun experimenting and simultaneously gain valuable insight into the process. Any physics handbook contains numerous other series for students that wish to go further.

```
LIST
100  REM FOURIER SERIES
110  LET S=15
140  LET P=3.14159
145  INPUT N
150  DEF FNA(X)=(4/((2*J-1)*P))*SIN((2*J-1)*P*X/5)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.001 STEP .5
202  LET Z=0
204  FOR J=1 TO N
206  LET Z=Z+FNA(X)
208  NEXT J
210  LET Y=INT(S*Z+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I";TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?1
 ------------------------------------------------------------
                              *
                              I     *
                              I          *
                              I              *
                              I                 *
                              I                  *
                              I                 *
                              I              *
                              I          *
                              I     *
                              *
                        *     I
                   *          I
               *              I
            *                 I
           *                  I
            *                 I
               *              I
                   *          I
                        *     I
                              *

READY
```

Exercise 25(a)

```
RUN
?2
 ------------------------------------------------------------
                              *
                              I          *
                              I                *
                              I                *
                              I             *
                              I            *
                              I             *
                              I                *
                              I                *
                              I          *
                              *
                   *          I
             *                I
             *                I
                *             I
                 *            I
                *             I
             *                I
             *                I
                   *          I
                              *

READY
```

Exercise 25(b)

```
RUN
?4
 ------------------------------------------------------------
                              *
                              I                *
                              I              *
                              I             *
                              I               *
                              I             *
                              I               *
                              I             *
                              I              *
                              I                *
                              *
             *                I
               *              I
                *             I
              *               I
                *             I
              *               I
                *             I
               *              I
             *                I
                              *

READY
```

Exercise 25(c)

```
RUN
?20
 ------------------------------------------------------------
                              *
                              I             *
                              I              *
                              I              *
                              I              *
                              I              *
                              I              *
                              I              *
                              I              *
                              I             *
                              *
                *             I
               *              I
               *              I
               *              I
               *              I
               *              I
               *              I
               *              I
                *             I
                              *

READY
```

Exercise 25(d)

EXERCISE 26 – An Unknown Wave Form

The unknown function is a ramp function that is clearly defined when 20 terms are included in the series.

```
LIST
100  REM FOURIER SERIES
110  LET S=15
140  LET P=3.14159
145  INPUT N
150  DEF FNA(X)=(2*(-1)↑2/(J*P))*SIN(J*P*X/5)
160  FOR I=1 TO 60
170  PRINT TAB(I);"-";
180  NEXT I
190  PRINT
200  FOR X=0 TO 10.001 STEP .5
202  LET Z=0
204  FOR J=1 TO N
206  LET Z=Z+FNA(X)
208  NEXT J
210  LET Y=INT(S*Z+30.5)
220  IF Y>30 THEN 260
230  IF Y<30 THEN 280
240  PRINT TAB(30);"*"
250  GOTO 290
260  PRINT TAB(30);"I"; TAB(Y);"*"
270  GOTO 290
280  PRINT TAB(Y);"*";TAB(30);"I"
290  NEXT X
999  END

READY
```

```
RUN
?1
 -------------------------------------------------------------
                              *
                              I  *
                              I     *
                              I       *
                              I        *
                              I         *
                              I        *
                              I       *
                              I     *
                              I  *
                              *
                           *  I
                        *     I
                      *       I
                     *        I
                    *         I
                     *        I
                      *       I
                        *     I
                           *  I
                              *

READY
```

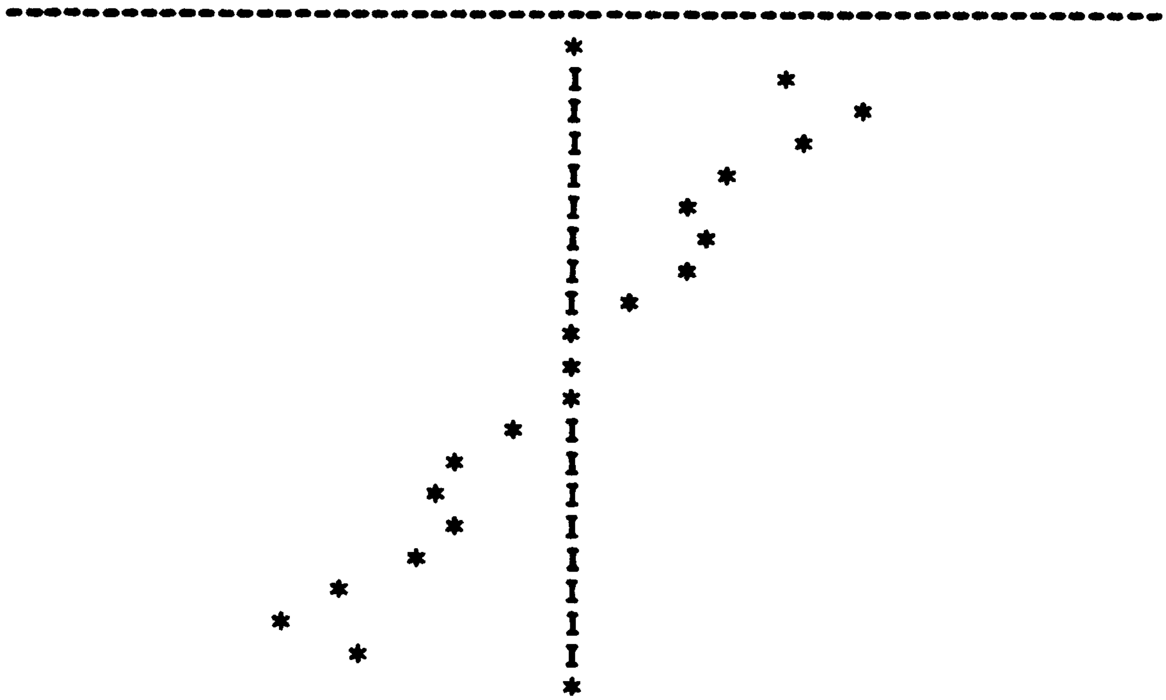
Exercise 26(a)

```
RUN
?2
 -------------------------------------------------------------
                              *
                              I     *
                              I         *
                              I           *
                              I           *
                              I         *
                              I     *
                              I  *
                              I*
                              *
                              *
                              *
                             *I
                           *  I
                        *     I
                    *         I
                  *           I
                  *           I
                    *         I
                        *     I
                              *

READY
```

Exercise 26(b)

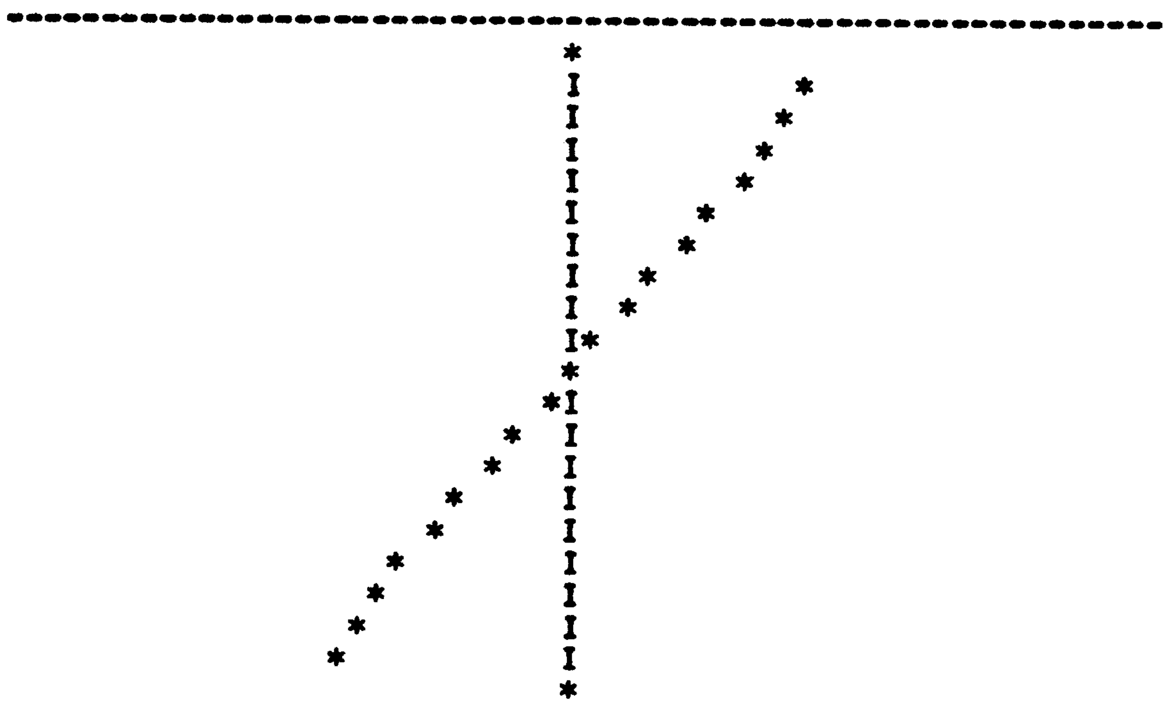
```
RUN
?4
```



```
READY
```

Exercise 26(c)

```
RUN
?20
```



```
READY
```

Exercise 26(d)